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Abstract

High altitude balloons provide a simple, inexpensive, and reliable means of studying planetary atmospheres. In recent balloon flights conducted by the University of Idaho’s RISE (Research Involving Student Engineers) Near Space Engineering program, the ascent rate and trajectory of the balloon path have been a major concern. Anomalous variations in ascent rate have been observed near the tropopause on recent flights. Simple models indicate that ascent speed should be essentially constant with altitude. However, near the tropopause a virtually instantaneous reduction in ascent rate of approximately 50% has been observed. Several possible phenomena to explain this effect are being studied, including changes in drag coefficient near Reynolds number of 3x10⁵ and a temperature induced loss of buoyancy due to cooling of the lifting gas during adiabatic expansion of the balloon in the near-isothermal layer above the tropopause (temperature drag effect).

Background

Idaho RISE is an interdisciplinary student run program sponsored by the NASA Idaho Space Grant Consortium. In the past eight years, Idaho RISE has had over twenty balloon flights, using high altitude balloons to carry scientific instrumentation to altitudes up to 100,000 ft. For the past several flights an anomalous change in ascent rate has been noticed. This effect has been studied in some detail during the flight of the NASA Ames - Naval Post Graduate School flight of Snowflake, an autonomous parafoil system that is set to be cut away from the balloon at a predefined time. RISE had one flight carrying Snowflake in October of 2010 in which cutaway was not performed. The second flight of Snowflake in the spring of 2011, had a successful cutdown, and both payloads along with data were recovered. In both flights, the ascent rate anomaly was seen.

Theory

Basic assumptions made in determining ascent rate model

- Balloon is spherical
- Internal pressure and temperature of the balloon is equal to atmospheric (external) pressure and temperature

In terminal ascent, upward force due to buoyancy is balanced by force of atmospheric drag. Ascent speed is found to be proportional to -1/6 power of atmospheric density.

Buoyancy $F_{buoyant} = \frac{4}{3} * \pi * r^3 (\rho_{air} - \rho_{He}) - mg$

Drag $F_{drag} = \frac{1}{2} * \rho_{air} * V^2 * C_d * A$

Result $V = \left(\frac{1}{R_{air} \rho_{air}}\right)^{\frac{1}{6}} \sqrt{\frac{g}{C_d}} \sqrt{\frac{8}{3} \left(1 - \frac{R_{air}}{R_{He}}\right) \frac{p_o^{\frac{1}{3}}}{T_o^{\frac{1}{3}}} r_o - \frac{2}{\pi} \frac{m}{r_o^2} R_{air} \frac{T_o^{\frac{2}{3}}}{p_o^{\frac{2}{3}}}}$

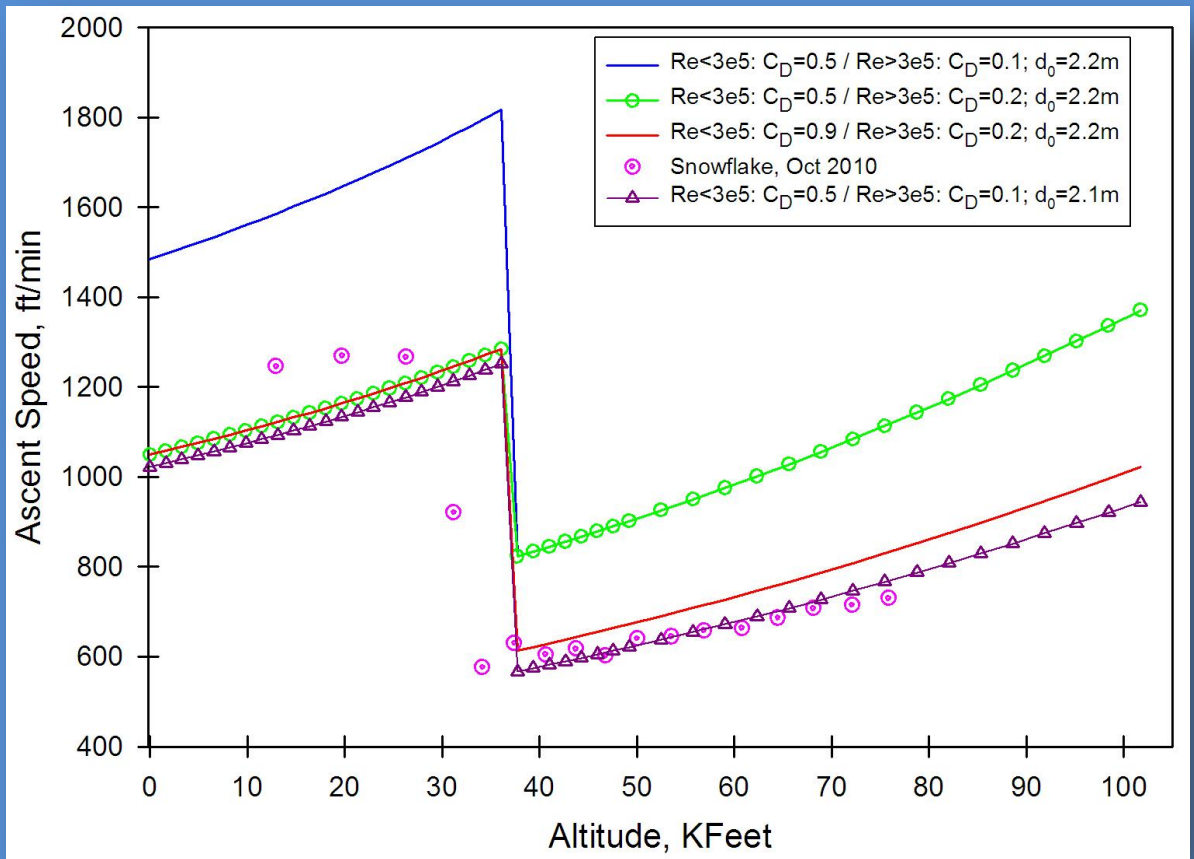
Possible causes considered

- A change in drag coefficient is the most likely cause of varying ascent rates. This corresponds with the Reynolds number change from less than 3e5 to greater than 3e5.
- A small leak in the balloon may be releasing helium from the balloon. This could happen at the balloon’s fill tube. However, this type of problem would result in a very slow decrease in ascent rate, which doesn't fit the data collected on the past few flights.
- Atmospheric waves/down drafts near the tropopause region could be adding downward force on the balloon. This behavior could possibly be oscillatory and slowly varying. Again, this doesn't fit the data.
- A temperature induced loss of buoyancy may occur where helium cools at altitudes within the tropopause as air temperatures remain constant. In this case the higher density of the cold helium would cause less lift

Variables:

| | | | |
|--------------|---------------------|----------|---------------------------------|
| ρ_{air} | Density of Air | R_{He} | Gas constant of Helium |
| ρ_{He} | Density of Helium | P_o | Initial atmospheric pressure |
| r | Radius of balloon | T_o | Initial atmospheric temperature |
| V | Balloon volume | A | Cross-sectional area of balloon |
| C_d | Coefficient of drag | V | Ascent Rate |
| R_{air} | Gas constant of air | | |

Varying Coefficient of Drag Theory



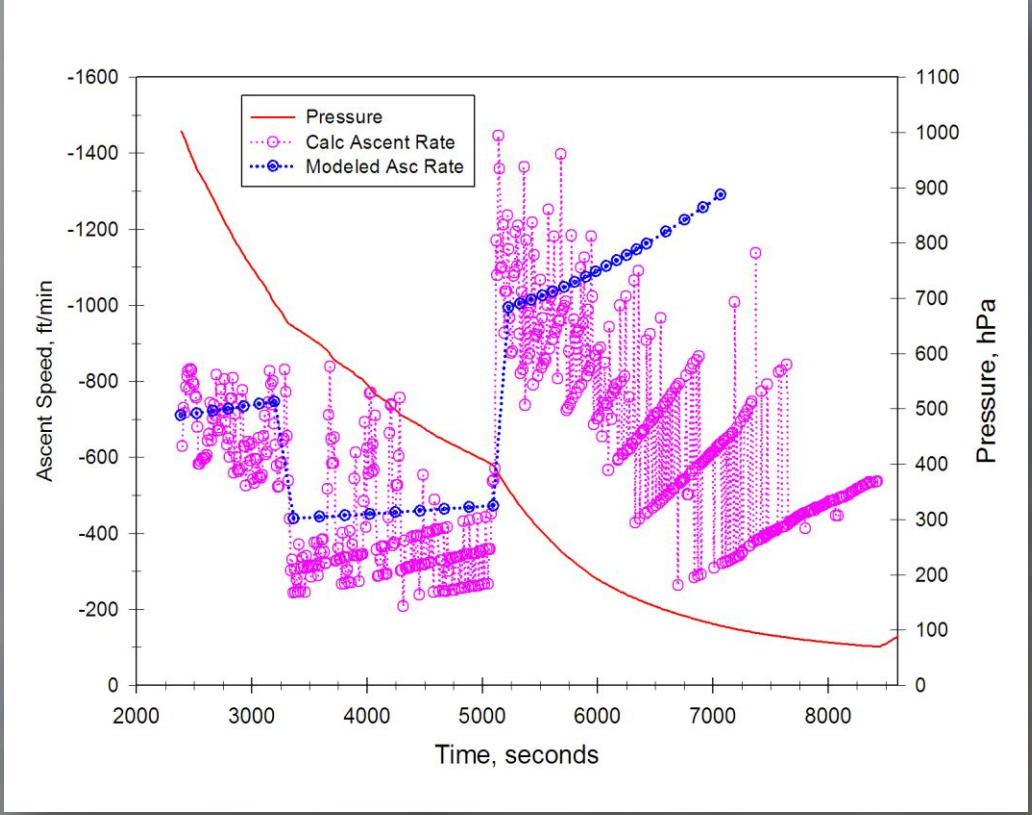
- Plots of ascent rate compare Snowflake flight of October 2010 to simple model with varying coefficients of drag
- Coefficients of drag are given for hard spheres. This information was taken from NASA research on drag of a sphere for rough and smooth surfaces at <http://www.grc.nasa.gov/WWW/K-12/airplane/dragSphere.html>

Snowflake Launch Spring 2011

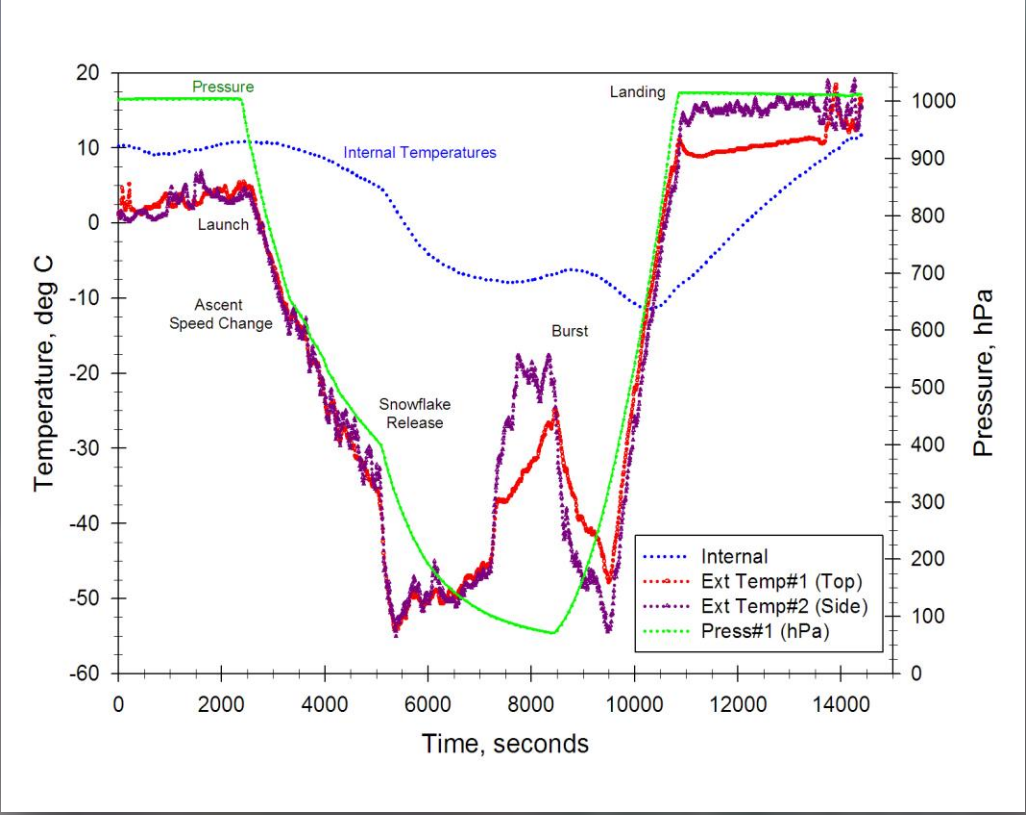
The VAST team capsule was equipped with an onboard cameras taking stills every 15 seconds. This gave us a direct look at diameter change for the entire flight.



Balloon diameter increase of 24% throughout flight. This increase closely matches those found in simple theoretical model.



Calculated ascent rate is from on-board pressure and temperature measurements. The step variations in ascent rate are due to finite word size of the pressure measurement.



Snowflake was cutaway at an altitude near 27,000 ft. and a pressure near 380 hPa during the Spring 2011 launch. Once again, the anomalous change in ascent rate was observed. The measured data fits theory fairly well except after Snowflake is cut away. Ascent rates measured based on pressure and temperature measurements show a significantly decreasing ascent rate. This has not been explained.

Conclusions

- A sudden change in drag coefficient is the most likely cause of varying ascent rates. This observed change occurs near the Reynolds number regime where experiment have shown drag coefficients to change.
- The curves of drag coefficient vs. Reynolds number for hard spheres can only be considered a rough approximation for the drag coefficient expected for a balloon.
- The observed decrease in ascent speed following Snowflake release is not understood. This can be modeled if we assume a drag coefficient that continues to increase with altitude, but there is no known theory that predicts such a phenomenon. This effect is still not understood and is still being considered.

Acknowledgments

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